International Transport Forum

The Social Impacts of Road Pricing
Summary and Conclusions

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Roundtable

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The International Transport Forum

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International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
contact@itf-oecd.org
www.itf-oecd.org

ITF Discussion Papers

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Executive summary

What we did

This report examines the distributional impacts of road pricing. It focuses on road pricing systems that are differentiated by time of use and location and on strategies to minimise or mitigate any negative distributive impacts. Road pricing has been advocated by economists as the efficient way to manage congestion. It is controversial because, on introduction, some existing road users gain while others lose. However, experience shows that where road pricing has been introduced, the new norm is rapidly accepted and pricing is then supported by the overall population affected.

The report presents the results of an ITF Roundtable held in Auckland, New Zealand, in December 2017. The Roundtable brought together around 18 experts from eight countries. The experts considered input papers on the relation of road pricing to peak demand pricing on public transport (Proost 2017), how a more optimal allocation of road space can improve social welfare (Crozet and Mercier, 2017), assessment of two road pricing schemes in Sweden (Börjesson, 2017) and the kind of detailed modelling required to understand and mitigate or minimise any negative impacts (Anable and Goodwin, 2017). Discussions also covered experience with the road pricing scheme in Singapore and presentations from Australasia, Dutch and ITF experts on the value of detailed modelling.

What we found

Road pricing provides an effective way to manage congestion. The alternative to pricing congestion is queuing. While levies that increase the cost of using cars, such as congestion charges, parking fees and fuel taxes can be regressive, they have been found to be progressive in some circumstances.

The revenues from fuel taxes will decline as vehicles use less fuel due to higher efficiency and electrification. Governments will need to make up the funding shortfall, taxing road use through other means. Electronic road pricing that is differentiated by time and place would provide an opportunity to align prices for road use with the marginal cost of using roads.

From an urban planning perspective, road pricing is as much about containing the demand of car drivers for road space as allocating road space between road users. A well-designed road pricing regime will reduce incentives for urban sprawl and less land will be needed for expanding road capacity.

Applying peak pricing to public transport fares in order to balance demand and fund additional services in the peak could bring large improvements for users with or without road pricing. Improvements come from reduced crowding and reduced boarding delays in public transport as well as reduced congestion on the road as some car-users switch to better managed public transport. Peak pricing on public transport could accompany road pricing as in cities with an already high share of public transport use, adding public transport capacity or lowering prices when road pricing is introduced is likely to bring less benefit than peak pricing.

Most studies find the overall distributional impact of road pricing schemes to be small. However, there can be households in pockets of urban areas that are seriously adversely affected. Disaggregated spatial analysis is useful to help design road pricing schemes to reduce the number of vulnerable households affected and indicate where investments in public transport can most effectively provide an alternative to car use.

Fraud is a consideration as many types of exemption and targeted assistance provide opportunities for fraud. If households vulnerable to having mobility curtailed by road pricing are spread sparsely across cities, location-specific mitigation measures are unlikely to be an efficient way to address negative social impacts. Regardless of whether road pricing is introduced, the tax and social security system is always the most powerful mechanism for protecting vulnerable households.

What we recommend

Make demand management and congestion reduction the primary objective of road pricing

The primary objective of road pricing should be to cut congestion and manage demand for the use of private vehicles. Other forms of taxation that cost less to administer are recommended if the objective is simply to raise revenue.

Differentiate road pricing by location and time

Price road use with differentiated kilometre charges to manage congestion and demand. This is much more efficient than using proxies such as fuel tax alone. The size of distributive effects will depend on travel patterns by income group and the spatial location of jobs and residential zones. The blunter the pricing scheme the more adverse impacts result because users are not priced strictly according to use. Fine differentiation of pricing by time of use allows travellers to select their preferred departure time to match their willingness to pay. This enables most users to adjust travel patterns rather than be priced off the road, minimising distributional impacts.

Combine road pricing and public transport planning to improve efficiency

Road pricing needs to be planned in conjunction with the operations of additional public transport services. Peak pricing should be considered for public transport, with or without road pricing, if current prices are low and the share of public transport use is already high. Service frequency should be increased in peak periods to the extent that peak pricing covers the additional cost. Where alternatives to car use are inadequate, major investment in public transport systems and pedestrian and cycling infrastructure is called for. Some cities with more dispersed land use and trip patterns may find such alternatives to be viable only on part of the network in the short term but should plan for more transit oriented development over several decades. The revenue collected from road pricing is a possible source of some of the funding for investment in and operation of alternatives to car use.

Examine the combined effects of scheme design and mitigation to understand distributional impacts

The overall distributional impacts of road pricing are highly dependent on the specific design of the scheme, in particular the location of cordons, when cordons are used as part of the scheme design. Whether these effects could be mitigated or compensated for through other components in the fiscal system will need careful assessment and would also depend on the detailed design of the pricing options. Assessing the social and distributional impacts of road pricing requires examination of vulnerability by location based on a mix of income, cost burden and adaptive capacity. However, as the overall distributional impact of time-differentiated pricing is likely to be low, it may be sufficient to rely on simpler approaches for assessing distance, time and location-based network-wide road pricing.

Consider the use of discounts and exemptions carefully

Exemptions and discounts have been used to improve the acceptance of road pricing schemes and target assistance to user groups but can jeopardise the effectiveness in managing congestion and are open to fraud. This has been the case with the London Congestion Charge. Exemptions and discounts for any users other than emergency services and public transport should only be considered after careful assessment of their impact on congestion.

Develop road pricing as part of an intervention package to achieve better utilisation of urban space

Road pricing will incentivise more efficient use of the roads, which should have a similar effect to building new roads in increasing productivity and improving access to jobs. Coupled with investment in public transport, road pricing will drive more transit oriented urban development and contain sprawl. Better utilisation of road space will ultimately make city living more attractive, reducing commuting time and emissions of air pollution from traffic.

Reconcile economic, practical and political aspects in the design of road pricing schemes

The cordon charges for road use that are in operation, and also the proposed schemes that have been turned down, suggest that particular care must go into the design of road pricing proposals. Economic theory provides invaluable input to scheme design but thorough exchange between decision makers and experts on the design of congestion pricing schemes is essential. Expert assessment is important as an evidence-based scheme that can increase benefits and reduce negative side-effects, but practical issues are equally important as implementation is ultimately a political process.

Differentiate charges and consider adopting a rules-based pricing approach

The London, Stockholm, Gothenburg and Singapore cases are all different and have, above all, different histories. A careful analysis must be made of the extent to which different components can be adapted to potential road pricing systems elsewhere. Nevertheless, differentiating charges by time and location, according to the distribution of congestion, will always reduce distributional impacts.

Singapore has enjoyed general support for road pricing from the population as their rules-based pricing approach has made the policy apolitical and provided reassurance that tolls are not adjusted to increase revenues but, instead, are regularly corrected to maintain levels of service. This approach to pricing also removes the need to conduct sophisticated modelling to set or modify prices.

Road pricing and its social impacts: Scope and objectives

Economists have advocated road pricing as the efficient way to manage congestion since the seminal work of Pigou (1920) that inter alia examined the external costs of travel demand. He proposed what have become known as pigouvian taxes to internalise externalities such as pollution and congestion so that they are taken into account in the decisions taken by individual economic actors. This produces a more optimal allocation of resources.

On busy roads, adding unpriced capacity often provides only temporary relief from congestion. Additional capacity allows additional trips to be made and the system quickly returns to the equilibrium determined by the cost of delays and unreliable journey time imposed by congestion (Duranon and Turner, 2011; SACTRA, 1994). Careful use of pricing, differentiated by time and location, can improve greatly on rationing by queuing, guiding users to avoid peak periods, and to car-pool or shift to public transport and cycling where they can. Such pricing can reduce travel time variability significantly and contribute to a more optimal allocation of scarce urban space to roads and between road users.

Road pricing is controversial because, upon introduction, some existing road users gain while others lose. Drivers with a high value of time gain from reduced journey time, as does much commercial traffic that can pass costs on. Drivers with a low value of time and low capacity to pay lose by being obliged to change departure times, switch to a less convenient mode or pay a charge that exceeds the value of their time-savings. It is also controversial because the revenues raised are typically larger than the direct benefits to drivers; the biggest benefits fall to the community more widely, including people using public transport.

Experience shows that where road pricing has been introduced, the new norm is rapidly accepted and pricing is then supported by the overall population affected. However, concern over distributional effects is clearly legitimate whenever a public policy intervention creates gainers and losers. Moreover, a number of proposed cordon charging systems have been rejected largely because they were perceived to be unfair by some road users, as for example in Edinburgh. Fairness in relation to the impact of tolls according to where people happen to live and work (horizontal equity) has been as much an issue as the potential impact on vulnerable low-income households (vertical equity).

The roundtable meeting convened by the International Transport Forum in Auckland in December 2017 examined recent work on the social impacts of time and space-based road pricing. The context for the discussions was provided by New Zealand Transport Minister, Phil Twyford, who underlined the importance of developing a multi-modal transport system where outputs are managed to provide the best possible outcome for citizens. He also emphasised the role of transit (public transport) oriented development for shaping the growth of cities and the importance of making housing and land markets more efficient. Large cities need investment in public transport as the only way to move large flows of people at peak times and provide a reliable alternative to the car. Road pricing is an important demand management tool and has the potential to steer land use patterns to maximising benefits. He noted that a failure to provide public transport is likely to have a far more regressive impact than charging for congestion on the roads. The Minister highlighted the need to better understand the interplay between public transport and road pricing and stressed the importance of understanding the social and distributional impacts of demand management policies.

The objectives of the roundtable were to:

- understand the current state of international practices in conducting social and distributional impact analysis, specifically applied to road pricing assessment
- share information on mitigation strategies to minimise the negative social and distributional impacts and maximise the effectiveness of such strategies
- explore recent developments in social impact assessment and modelling methodologies used to inform policy design, enhance transparency and identify and mitigate risks.

Work commissioned for the roundtable included a paper on the relation of road pricing to peak demand pricing on public transport (Proost, 2018) and a paper on the function of road pricing as part of a full range of instruments for integrated land use and transport planning to achieve a more optimal allocation of space in an around cities (Crozet and Mercier, 2018). Discussions covered Singapore, where road pricing has been applied since 1975 as part of a full set of integrated planning instruments, demonstrating how road pricing can be used to fine tune speeds and schedule delay. Assessment of two road pricing schemes in Sweden revealed the broader social impacts of pricing and a high degree of public support for the systems today temporarily and spatially (Börjesson, 2018). Several presentations identified the importance of detailed modelling and differentiated pricing in achieving the maximum benefit from road pricing. Work underway in New Zealand on the assessment framework required to understand the distributional impact of road pricing was discussed together with the kind of detailed modelling required to understand and mitigate or minimise such impacts from theoretical charging schemes in the UK (Anable and Goodwin, 2018; Bonsall and Kelly, 2005).

This report is organised as follows. The first section looks at the theory and practice of charging for road use. Then it examines international experience in assessing and mitigating the distributional impacts of road pricing. The third section establishes a framework for the evaluation of distributional impacts and reviews recent developments in related modelling techniques. The report closes with a discussion of findings that are transferable to the development of a potential road charging system for Auckland.

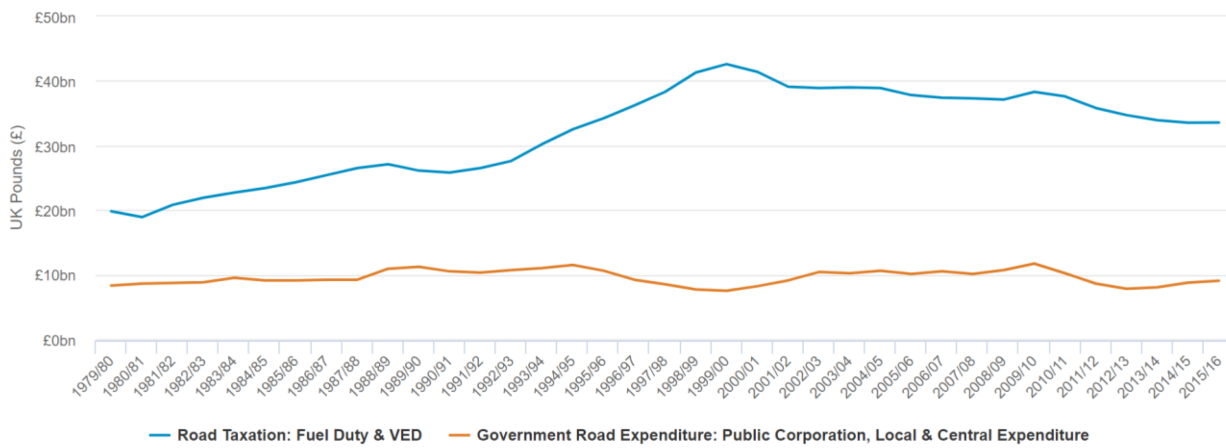
Theory and practice of charging for road use

Current practices

Current taxes and charges related to road use vary greatly across ITF member countries, both in absolute terms and in relation to expenditure on the roads. In some countries, fuel excise and vehicle duties are generally insufficient to fund the investments required to meet demand. In others the revenues exceed expenditure. In the UK, for example, fuel and vehicle excise duty produced revenues roughly three times expenditure on the roads (Figure 1). The extent to which revenues from these taxes and charges are earmarked to spending on road or transport infrastructure also varies greatly. In the US, the Federal Highway Trust Fund (which now also funds transit investments) was financed entirely with dedicated funds from Federal fuel taxes until 2008, when transfers from General Funds began to be required to ensure the Fund remained solvent. Since then the gap has widened with fuel taxes frozen in nominal terms and fleet average fuel economy improving. In 2016 general funds contributed twice the amount of the dedicated fund.

The reason why taxes on motoring are used in some countries to contribute to general government revenues well in excess of road expenditure is that demand is relatively inelastic. Taxing car use is less distorting than taxing more elastic consumption of goods and services as it has less impact on the allocation of resources in the economy.

Figure 1. Public road expenditure and taxation in Great Britain (inflation adjusted at 2015/16 prices)



Source: RAC Foundation (using data obtained from the UK Department for Transport to 2016/17).

The revenues from fuel taxes are declining in most OECD countries as vehicles become more fuel efficient, driven by regulatory and fiscal incentives under climate change policies. As electric vehicles penetrate the market this trend will intensify and if the ambitious goals for decarbonisation of the sector set by many countries are met, fuel tax revenues will eventually be extinguished. Governments will need to make up this shortfall and taxing road use by kilometre driven rather than fuel consumed is an option. Increasing taxes on car purchase and ownership is another alternative.

Box 1. Road user charging in New Zealand

Road User Charges (RUC) were introduced in New Zealand in 1978 as a means of more efficiently charging for road use by heavy vehicles and to provide a level playing field for rail and road freight competition. It replaced fuel excise duty on diesel and applies to both heavy vehicles over 3.5 tonnes and light-duty diesel vehicles. A cost allocation model is used to distribute road wear and common costs between categories of vehicles considering space use, vehicle weight and distance travelled. The model is regularly run when changes to RUC are considered and the model itself is updated periodically and was last updated in 2015. RUC is one of the main revenue sources to the National Land Transport Funding (NLTF) in New Zealand and accounts for around 40% of its revenue. Other key funding sources include fuel excise duty for petrol and gas powered vehicles (around 54%) and motor vehicle registration and licensing fees (around 6%). The NLTF funds road improvements and maintenance, road safety, public transport, walking and cycling. Local authorities additionally contribute just under half of the total cost of improving and maintaining local roads and public transport.

The New Zealand Government has recently introduced a regional fuel tax for Auckland to raise revenue for transport sector investment, at least some of which will be investment in public transport. The regional fuel tax applies to sales of petrol and diesel in the Auckland region as of 1 July 2018. The rate is set at 10 cents per litre, which is less than the variation between retail prices within New Zealand.

A number of short, recently-constructed stretches of national highway are tolled in New Zealand, with flat rate charges to enter the tolled sections designed to recover costs. Tolls can only be applied to new roads and tolls are applied with fully electronic free-flow technology, with payment by internet account or at selected filling stations. Payment can be made before or after use or by automatic debit. Compliance is enforced with automatic number-plate recognition cameras.

For the longer term, traffic demand management measures, such as congestion pricing, are being investigated.

Principles for pricing congestion and road user charges

As Pigou (1920) discussed, the reference level for setting charges to achieve the economic optimum is alignment with marginal social costs. Marginal because we are concerned with the additional costs of adding one more user to the system, social because as well as private costs we are interested in the costs to other users of the transport system and to society as a whole, including impacts on safety and the environment. The relevant cost for congestion pricing is the cost of the congestion that an additional vehicle on the road inflicts on the other users of the road (i.e. the external congestion cost, external to the driver of the additional car). Both short- and long-run costs are important but the short-run costs provide the basis for charging for the use of transport infrastructure as explained in the following passage from an earlier ITF report (ECMT, 2003):

> *There are two fundamental aspects to efficiency: efficient use of the infrastructure that exists and, over the longer term, efficient provision of transport infrastructure in terms of quantity and quality. The use of any road, railway, waterway and port, etc., is optimised when its traffic is charged the short run marginal costs of using it. When there is ample capacity, charging for the use of infrastructure is made according to the following main categories of cost: maintenance and administration; emergency services and other external accident costs; air and noise emissions. When there is a capacity shortage, especially during peak hours and at pinch points, a demand*

management charge should be used to balance demand with capacity — in place of rationing by congestion. This should ensure that capacity is reserved for the highest value uses.

When demand management charges reach levels that generate sufficient revenues to finance expansion of capacity, this should be a trigger for an assessment of the potential benefits of investing in additional infrastructure. The assessment would have to go beyond financing to consider the full range of costs and benefits that affect economic welfare, including the opportunity costs (for example of land cleared that could instead be used for housing and offices, etc.) and impacts on landscape, water courses and biodiversity. Projects that pass assessment would proceed in order to ensure efficient development of transport infrastructure.

When congestion is present and charged for, the capital costs of roads will normally be recovered. Where there is no congestion, optimal pricing could leave these costs uncovered. Treating transport infrastructure as a public good, these costs should be met through general taxation. In cases where governments seek to recover some or all of these costs directly from users it is most efficient to do this through fixed charges (such as annual road taxes) in order not to price-off beneficial use of the capacity available (although this can present different challenges around enforcement of such charges and can have mild regressive impacts on access to private motoring).

Optimising the allocation of urban space and optimising the use of roads

The community is concerned about the use of urban space whereas individuals are concerned more about travel times. When individuals make travel decisions based only on average cost to them, there will be excess demand as the external costs to other users are ignored, with pressure to consume more space for roads than is optimal for the community.

In cities, the space for extra lanes is expensive. Congestion is often network-wide and at points of access to highways, rather than on specific links. Pricing only part of the road network is likely to be insufficient to manage congestion, although in Stockholm the effects of the central cordon are felt on the arterial roads across the urban area. Singapore has applied area-wide road pricing since 1975, with a system that began as a simple cordon and has become progressively more sophisticated, with tolling extended gradually along highways further out from the central part of the city. Tolls are varied by time of day and by the location of the charging gantry. Levels are reviewed every three months based on data on traffic speeds and adjusted where necessary to maintain speeds around 20-30 km/h on city roads and 45-65 km/h on expressways. The targets are based on traffic flow modelling of optimal speeds (Chin, 2010). Where prices have been increased the response is a 3 to 5% reduction in traffic. In one case, two successive price increases were required for the response on a particularly busy corridor. The system has proved effective, maintaining traffic flow as planned.

From an urban planner's perspective, Crozet and Mercier (2018) stress that optimisation of the use of urban space rather than increasing speed should be the key function of road pricing. Vehicles occupy more space at higher speeds, as the distance between vehicles for safe operation increases with speed. The design speeds in Singapore are in line with their findings, which suggest space consumption is minimised at speeds between 20 and 40 km/h. Traffic composed entirely by automated and connected vehicles would in principle allow higher speeds, but on city networks with frequent junctions and pedestrian crossings the impact would be negligible. Road pricing commoditises the use of scarce urban road space, with users paying for what they consume.

Better utilisation of existing vehicle capacity (e.g. use of shared mobility services) is another way to improve use of road space. While shared mobility may increase over time, road pricing can be a catalyst to speed up such behavioural change. Wide adoption of centralised door-to-door shared mobility services might result in significant reductions in congestion and emissions (ITF, 2017a). However, growing use of shared mobility also raises issues, for example, around the use of curb space for picking up and dropping off passengers and the management of idle vehicles that add to traffic between rides (ITF, 2018). In the absence of congestion pricing, any reduction in traffic achieved through shared mobility is in any case likely to be cancelled out by traffic drawn to the improved traffic flow conditions. In the absence of road pricing, congestion effectively "prices" potential users off the road. Releasing capacity through shared rides is likely to release pent up demand for car use in the same way as expanding roads, with congestion returning quite quickly to previous levels.

Road pricing increases economic output by sorting traffic. It allocates road space according to the value attached to the trip by each road user. It should be effective in achieving better matching of skills and opportunities in the labour market through this sorting mechanism, driving productivity and generating the kind of agglomeration benefits delivered by infrastructure investment. Peak charging in particular causes changes in commuting patterns and labour market matching. For example, Anderstig et al. (2016) found Stockholm congestion charges to have delivered positive labour market effects that are equivalent to 75% of charge revenue (of EUR 80 million per year). Expert labour is likely to gain most from this traffic sorting effect.

It was suggested in the roundtable discussions that the impact of road pricing on commuter traffic is perhaps revealed in the neighbouring French and Swiss towns of Annecy and Lausanne. Commuters on the French motorway system pay a toll with the result that a large number of commuters using the motorways ride-share. In Switzerland motorway access is subject to an annual fee rather than a toll. Most commuting trips on the motorways around Lausanne are made by solo drivers. Research on the full range of factors influencing behaviour, and covering tolled commuter roads elsewhere in the world, would be required to establish the extent to which tolling accounts for the difference in car occupancy between the two cities.

In Singapore road pricing is used to stabilise traffic speeds and journey time reliability in an integrated transport and land-use planning system, managed with a complete range of instruments (Chin, 2010). In common with other cities, on-street parking prices and dwell-time limits are key components in traffic demand management in Singapore's overall strategy. These play an important part in determining individuals' car use decisions. Parking space provision is regulated together with pricing for parking because insufficient parking space can exacerbate traffic. Minimum parking provision limits apply to new buildings but because the supply of parking places also incentivises car use, the rules currently allow developers to provide 20% less car parking than the minimum. Ownership of cars is managed through auctioned permits and purchase taxes that can be as high as, if not higher than, the value of the car (such auction systems are also used in some major Chinese cities). Public transport systems are well-developed in Singapore with the highest share of passenger traffic carried by bus. Housing and commercial developments are authorised in conjunction with extensions to bus services. Road pricing fine-tunes traffic demand at the apex of the suite of demand management tools.

Road pricing based on road use has been used successfully on highways to manage congestion in several places (e.g. High Occupancy Toll [HOT] lanes in California and Chinese Taipei's distance-based pay-as-you-go electronic toll collection system for using the national motorway network). Notably, on the I 15 highway in San Diego, a continuously varying toll provides access to reserved lanes that are priced to ensure flow on these lanes is always fluid (Supernak et al., 2002). Drivers have the alternative of using the adjacent, congested lanes. The solution is seen as fair because the toll pays for the extra lanes and, regardless of income (and the average value of time that implies), any driver can benefit on occasions that they have an imperative reason to take the uncongested lane and pay.

In Chinese Taipei, electronic toll collection was first introduced in 2004. It was applied as a fixed-charge tolling system for entry to the freeway network. This raised concerns over fairness as the system resulted in short commuting trips being charged the same rate as longer journeys on the network. Toll stations outside urban areas applied higher rates to counter this effect but that in turn was discriminatory towards people living near these entry points. In 2014, distance-based charging was introduced to improve efficiency and to overcome equity concerns, covering all classes of vehicle using 932 kilometres of tolled roads. To ensure public acceptance, a daily discount is currently applied, with the first 20 kilometres free of charge. Discounts are also available for long distance trips and during holiday periods. These concessions clearly undermine the value of the system for managing congestion. Nevertheless the Freeway Bureau estimates that electronic toll collection has reduced the travel time between Taipei and Kaohsiung (approximately 370 kilometres) by between 20 and 30 minutes. The Bureau plans to differentiate charge rates by peak and off-peak periods once road users are familiar with distance charging. It also plans a novel approach to peak holiday traffic. Demand is so intense before and after the major annual festival that the Bureau believes it is beyond any acceptable peak charge level to manage. For this period standard rather than peak charges will therefore apply, conceding that service standards cannot be maintained even with high prices.

Public transport pricing

Although travelling on public transport may take longer than by private car, space consumption per traveller is much lower at reasonable load factors. Congestion generated essentially by car traffic delays buses, affecting many more bus passengers than car drivers. In the absence of congestion pricing, second best approaches to managing urban traffic include subsidised public transport fares. When private transport is optimally priced, however, public transport pricing should be based on the same principles as pricing for road use; and should take into account of the marginal external cost of an additional user. Crowding on public transport increases boarding time, slowing travel speed. Crowding also results in discomfort that further reduces the welfare of users (ITF, 2014). Using simulation results for Stockholm and Paris, Proost (2018) shows that during peak and off-peak periods it is strongly welfare enhancing to differentiate public transport prices and vary frequency of service. Peak pricing helps to cover the costs of supplying capacity. When peak prices are too low, there is an excess demand for capacity and with a low revenue base it is difficult to improve or expand public transport services.

Public transport prices may also be set low for social inclusion purposes although a more effective approach is to aid vulnerable users directly. Bogota is one of the few cities to do this. Its SISBÉN system for identifying people eligible for support from social security programmes is also used to provide subsidised travel cards for public transport (ITF, 2017b).

Setting public transport prices too low increases operating deficits and leads to excessive demand, causing crowding and discouraging modal switch away from car use. For example, bus transport is not peak-charged in London and school children travel for free and 40% of all users enjoy concessionary fares. School children travelling for free account for 14% of all bus passengers (London Assembly, 2013). They use buses for short trips in place of walking. This unintended behavioural change – forces commuters off public transport. Many cities that have trialled or implemented free public transport services have found that even though it results in some modal shift from cars to public transport, a larger, undesired shift from walking and cycling has also been induced (e.g. Macharis et al., 2006; Van Goeverden et al., 2006; Cats et al., 2017).

Proost (2018) concludes that when public transport prices are set low and the share of public transport trips is already high, as is the case for most major cities, it is neither efficient nor effective to direct revenue from road pricing to further reduce public transport prices. Modelling results for Stockholm and Paris, he finds only very small welfare gains are achieved from this approach in contrast to the large gains from optimising prices and frequencies in relation to peak and off-peak demand on the public transport system.

For cities with insufficient public transport provision, improving services will increase socio-economic welfare, with or without road pricing. This effect is particularly important in developing economies, where transport consumes a major share of income for a large part of the population and where motorcycles may offer a cheaper alternative to public transport with their attendant crash risks, noise and air pollution costs. Any change in fares policy should be assessed for unintended consequences.

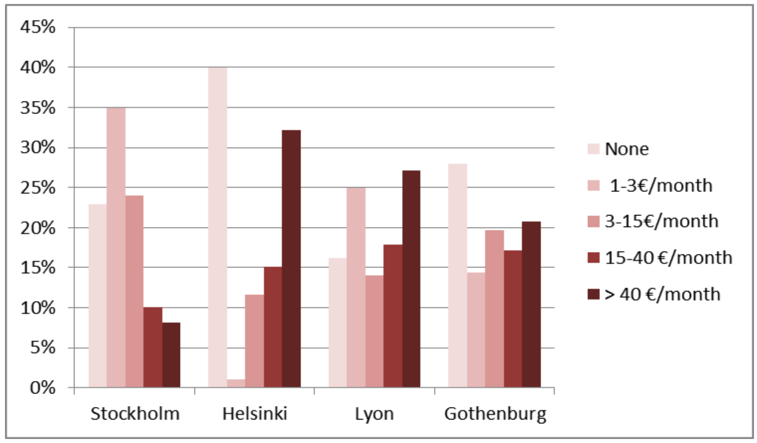
Understanding and mitigating social impacts

Results of modelling the overall social impacts of road pricing schemes in Europe

Eliasson (2016) examined the distributional effects of congestion pricing for an earlier ITF roundtable meeting (ITF, 2017b). He investigated the fairness of the congestion charges in Stockholm and Gothenburg and theoretical charging systems in Helsinki and Lyon, from consumer and citizen perspectives. His consumer analysis takes a standard economic welfare assessment approach, with welfare effects falling in four parts: the tolls paid; the cost of adapting travel patterns to the charges; the value of travel time gains; and the benefit of recycled revenues. Eliasson first examined the equity effect of the toll payments alone; noting that use of the toll revenues is crucial, even if the amount of tolls paid is a good proxy for the rest of the overall welfare effect. The results are instructive.

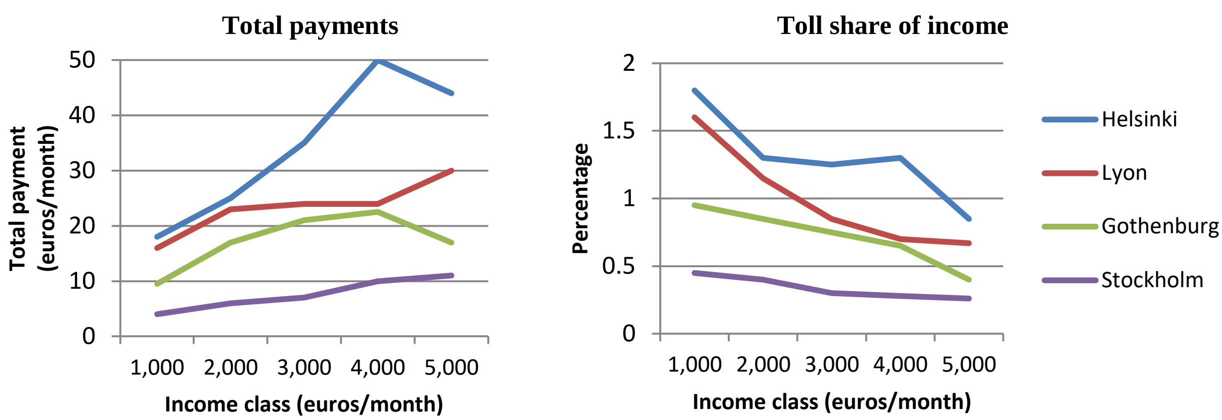
The first point is the very different incidence of the tolls across the population in the four schemes (Figure 2). In all four cases the design results in higher income groups paying higher amounts of toll (Figure 3, left panel) although in two cases the high income group pays less than some middle income groups. In Helsinki this is because those with the highest incomes tend to live and work in the city centre and have shorter trips. In Gothenburg it is because company cars are exempt from the charge under Swedish tax law. Even if the poor pay less than the rich they do pay a higher share of their income in tolls (Figure 3, right panel). Eliasson assesses their impact using the Suits Index (Suits, 1977) and compares their effects with some other transport sector charges and other taxes (Table 1). The tolls in Stockholm and Helsinki are slightly regressive and those in Gothenburg and Lyon moderately regressive but no more regressive than the other taxes assessed.

Figure 2. Share of population who pay various amounts in tolls



Source: Eliasson (2016).

Figure 3. Average toll payments by income class



Source: Eliasson (2016).

Table 1. Regressivity/progressivity of congestion charges and other taxes

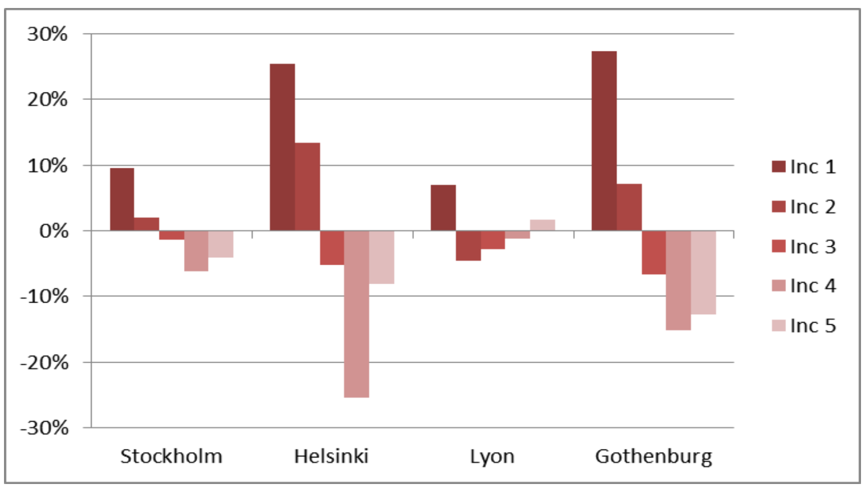
Tax or charge	Suits Index	Study
Stockholm congestion tax	-0.09	Eliasson, 2016
Helsinki congestion charge model	-0.09	Eliasson, 2016
Gothenburg congestion tax	-0.13	Eliasson, 2016
Lyon congestion charge model	-0.16	Eliasson, 2016
Swedish fuel tax	+0.03	Eliasson, 2016b
Swedish differentiated vehicle tax	-0.09	Eliasson, 2016b
United States vehicle miles travelled tax	+0.14	West, 2004
United States differentiated vehicle tax	-0.30	West, 2004
United States sales tax	-0.11	Metcalf, 1996
Texas gasoline tax	-0.25	CPPP, 2007
Texas sales tax	-0.18	CPPP, 2007

Note: The Suits Index is bounded by -1 and +1. A flat rate tax has an index of 0, a progressive tax has a positive score and a regressive tax a negative score.

Source: Eliasson, 2016.

Eliasson (2016) also examined attitudes to congestion charges by income group, broadening the assessment to cover a fuller range of variables relating to self-interest. The number of cars in the household, the value of time savings and the number of car trips taken are considered as well as the cost of toll payments. Households were surveyed in the four cities and asked how they would vote in a referendum on congestion pricing. Very little difference in attitudes was found between income groups. Moreover, in modelling the costs and benefits of each group, Eliasson found very little difference in attitudes to paying one more euro in tolls, one more car trip etc. The effect in relation to any of the variables tested seemed to be the same regardless of income, probably because for the moderate size of the sums considered; differences in the marginal utility of money are not large enough to affect attitudes. Figure 4 shows Eliasson's results for how much better or worse off each income group perceives itself to be on average compared to the average citizen in that city after introduction of congestion charging. Patterns are remarkably similar, with the lowest income groups benefiting most.

Figure 4. Average "compound self-interest" by income group, relative to the mean in each city



Source: Eliasson, 2016.

With this perspective, congestion charging appears "progressive". Lower income groups are hurt less, as perceived by the individuals themselves, on the basis of how self-interest variables influence voting response. Eliasson then goes on to examine fairness from a "citizen perspective", on the basis that depending on an individual's views of procedural fairness and views on equity and environmental issues, congestion charging can be viewed as more or less fair in an abstract sense regardless of the direct consumer effect. Winners from congestion pricing reform are people who approve of the underlying rationale of congestion pricing. Eliasson produced a model to identify how consumer variables and social attitudes affect views on congestion pricing. He found that from the "citizen utility" point of view (fairness in relation to social attitudes) it is the middle class that benefit most from congestion pricing.

Eliasson's findings are consistent with those of Van den Berg and Verhoef (2011), who examine heterogeneity in values attached to scheduling preferences and travel time using a bottleneck model of congestion. A standard result from the economic literature is that, when rescheduling is neglected, users with a high value of time gain and those with low value of time lose. Although the value of time is a weak proxy for income, this is often taken as implying that the poor lose and the rich gain. Van den Berg and Verhoef found that this is no longer true if users significantly reschedule their trips and if the main form of congestion is queuing behind bottlenecks. In fact in this case, a majority of travellers are better off with congestion charging, even when the toll revenues are not redistributed to drivers. The main reason is that the very fine differentiation of tolls over the day enables spreading of demand so as to dissipate most of the queuing. The time lost due to queuing is transformed into payments for road use. Moreover, it is not users with the lowest value of time that incur the greatest losses, or enjoy the smallest gains. This suggests that it is important to include schedule delay costs as a standard component in the assessment of distributional impacts of congestion pricing. Van den Berg's conclusion is that where congestion mainly takes the form of bottleneck delays, for example mainly at access points to arterial roads, peak and shoulder pricing can be used to spread peak demand sufficiently to cut congestion whilst avoiding pricing most lower income users off the road, as almost all car users can reschedule rather than cancel trips.

Eliasson concludes that it is hard to find much support for the view that congestion pricing is unfair, if its purpose is to correct prices and allocate scarce resources more efficiently. Both in terms of absolute payments and self-interest, lower income groups fare better than average. From a citizen perspective, differences are small, but lower income groups fare at least as well as high income groups. This changes, however, if the purpose of the charging system is in fact to generate revenues. In that case, the (slight) regressivity of pricing systems is a serious problem: it is difficult to defend making poor groups contribute more than proportionately to public revenues.

Cain and Jones (2008) narrow the assessment of the distributional impacts of congestion charging to the issue of most concern: does it cause hardship to low income car users and their dependents? They examined the proposed Edinburgh congestion charging scheme, rejected in a referendum in 2004, using national Family Expenditure Survey data and the Scottish Household Survey. The authors defined hardship in terms of affordability criteria developed in the utilities sector and set three conditions for road pricing to result in hardship:

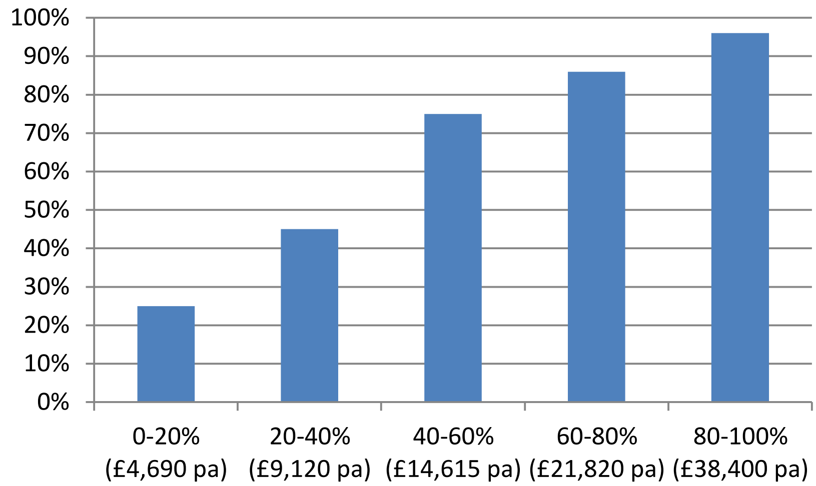
1. The charge payment (or a series of charge payments) would breach affordability criteria.
2. No reasonable alternatives are available to enable the charge to be avoided.
3. A charged trip (or a series of charged trips) is required to access a basic need.

The Edinburgh scheme involved a weekday charge of GBP 2 for inbound crossings of either a city centre cordon or an outer cordon just inside a bypass ring road. The payment provided for unlimited cordon crossings that day. The central cordon charge applied 7 am to 7 pm while the outer cordon charge would have applied only in the morning peak, 7 am to 10 am. No charges were applied at weekends. The charge was part of an integrated scheme to develop public transport, using the charge to encourage modal shift, with revenues to be recycled into public transport.

Data from Cain and Jones shows that, for Scotland as a whole, only 25% of households in the lowest quintile income group spend any money on motoring (Figure 5). Figure 6 shows the proportion of disposable income used for motoring averaged for all households and for households with access to a car only (labelled as "Spenders Only"). This shows that car-dependent households on low incomes spent a much higher proportion of their disposable income on motoring. However, this data also illustrates another important point that focusing on impacts on car users only can ignore the largest (75% in this example) part of hardship and equity issues related to transport policy.

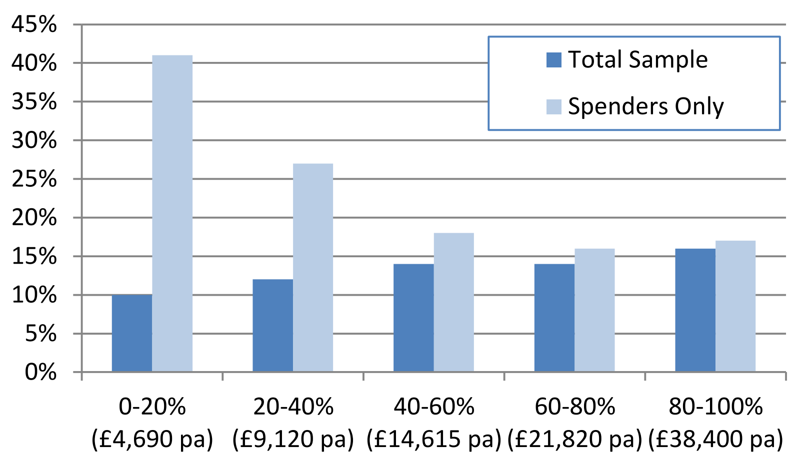
The low-income households surveyed did not regard motoring as a luxury but rather a necessity to reach basic needs and services and responded that they were no more likely to change their car use because of congestion charging than people in higher income groups. The charge would have increased hardship for the poorest drivers especially when they were already spending far above the affordability threshold defined by the study. For those in the poorest fifth of the population driving to work across the cordon, motoring costs would increase by up to 20%. This reinforces the need to look into disaggregated data to identify at-risk user groups and target mitigation measures. In some cases, varying charges by time of day may be sufficient to alleviate the road pricing impacts on some lower income earners who work night shifts or at isolated out of town developments and therefore have limited alternatives to car use.

Figure 5. Proportion of Scottish households in each income quintile incurring some motoring costs (%)



Source: Cain and Jones (2008).

Figure 6. Proportion of disposable income spent on motoring by income quintile in Scotland



Source: Cain and Jones (2008).

A number of studies on the social impacts of congestion charging in Stockholm and Gothenburg have been published (Börjesson and Kristoffersson, 2014; West and Börjesson, 2017). They find that distributional impacts are higher in Gothenburg because of the distribution of incomes and a high level of car dependency by all income groups. In Stockholm, incomes are much higher than average in the central core of the city, which is the area subject to the cordon charge. In Gothenburg there is no such relationship between where the tolls are charged and the distribution of households and trips by income group. Overall welfare benefit is much lower in Gothenburg. The charge in Gothenburg is designed to raise revenue rather than manage congestion, which is limited in scale.

There are significant differences in the spatial impacts of alternative pricing options. This has implications for the location, coverage and scope of the charging systems as well as the choice of possible mitigation measures. Eliasson and Mattsson (2006) looked at the net effects of congestion charging in Stockholm with different measures to channel revenue back to travellers. They assessed the net effect on users of total charges paid, the value of changes in travel patterns and the value of travel time savings (also referred as value of time). They found a consistent geographical distribution of net effect between the three revenue recycling options examined: a public transport refund scheme, a lump sum refund scheme and a tax cut refund scheme. They found that travel costs more towards the city centre and that the rural community benefits most from the recycling measures. Crozet et al. (2012) looked at the impacts of accessibility to jobs and found similar results using a homogeneous value of time, but the pattern was reversed when heterogeneous values of time are used. This underlines the need to consider the distribution of the value of time amongst users in order to understand the distributional impacts of charging.

Using administrative records (such as vehicle inspection data and income data) to develop a microsimulation approach, Mattioli et al. (2017) found diverse spatial patterns for the vulnerability dimensions studied (cost burden, income and adaptive capacity). They found that inner city areas tend to be less vulnerable but there are pockets of very high vulnerability between major urban areas. This finding supports the need to use disaggregated information rather than the traditional approach of focusing on average users.

Bonsall and Kelly (2005) modelled a range of potential congestion charging systems in Leeds. They found the populations of users vulnerable to road pricing under the different schemes to be scattered quite sparsely across the built-up area. This suggests location-specific mitigation measures would have been unlikely to be effective.

Perhaps surprisingly, once income is controlled for, distributional effects across different socioeconomic characteristics appear to be relatively small (Eliasson, 2016). He found exceptions in only a few cases; for example, households with young children would pay more than households without children in Lyon and Gothenburg and older people would pay less in Lyon.

Road pricing options and scheme designs

Road pricing can be applied in several different ways, summarised in Table 2. The choice of pricing option and scheme design can have a significant effect on how the impacts of road pricing are distributed between population groups and between locations. Modelling is important for setting the boundaries of area charges and cordons, for minimising rat-running and traffic diversion and for successfully targeting congestion and avoiding any drift towards simply revenue collection.

The most efficient charging system will charge according to scarcity, so it will charge by distance driven (road space consumed) rather than just when a cordon is crossed, and it will be higher at more congested times and locations. Prices might vary continuously, or vary according to fixed schedules by time of day and day of the week. And charges and charging schedules might be revised periodically.

The modelling that underpins Stockholm’s cordon charge, which incorporates peak and off-peak prices, suggested that most of the benefit in terms of congestion management could be achieved with a relatively simple system. Introducing charges just in the centre of Stockholm was beneficial over the whole of the region as congestion tended to back-up along corridors behind the bridge crossings where the cordon is applied.

Generally, however, the blunter the scheme the more losers there will be and the charging scheme needs to be sufficiently refined to target the congestion problem where it occurs. Singapore has the most sophisticated system in operation today as it is differentiated by time and location. As part of a full set of integrated land use and transport management tools, it is used to fine-tune traffic speeds. At the other extreme, Gothenburg applies peak and off-peak charges despite the absence of congestion outside the peak; it generates a net welfare loss (West and Börjesson, 2017). In London the once a day charge regime has proven ineffective in managing delivery vehicles for e-commerce, one of the fastest growing sectors of traffic. A fixed daily fee is also unsuited to managing taxis and app-based ride services, another fast-growing sector. Singapore's system is differentiated to the point that it has three daily pricing peaks (and charges are specific to each charging point). In addition to the morning and evening rush hours, a lot of offices schedule meetings at 2:30 pm generating a third peak in work day traffic. Simplicity might argue for just two peak periods but the rule-based pricing strategy for determining prices (see Box 2) has generated the triple peak charge.

Table 2. Options for differentiating road pricing systems

Type*	Main characteristics	Options		
		Scheme coverage	Fixed or variable charges	Other
Cordon charging	Charge for each crossing of a cordon delimiting the charging zone in a city	Location and size of cordon	Time of day Day of the week Number of trips Vehicle type Direction of travel	Exemptions Concessions Frequency of revising prices
Area charging	Daily charge for driving into or within a defined area but no additional charge for crossing cordon more than once	Size and location of area/s	Time of day Day of the week Vehicle type Distance travelled	
Corridor charging	Charges for passing points along a corridor in a city	Number and location of charging points	Time of day Day of the week Number of trips Vehicle type Direction of travel	
Variable tolls	Peak charges for already tolled highways and bridges	Local, Regional, National (dependent on toll network)	Time of day Day of the week Vehicle type Distance travelled	
Tolled lanes	Tolled lane on un-tolled road segment, often discounted/exempt for high occupancy vehicles	Number and location of charging points	Time of day Day of the week Vehicle type Vehicle occupancy	
Electronic time, distance and place-based charging	Uses transponders to enable charging of any use of the entire road network or a specified part of the network	Local, Regional, National, specifically congested routes	Time of day Day of the week Vehicle type Distance travelled	

* It is possible to combine features of more than one of the categories identified in this column and most road pricing systems do this in practice. For example, area charges usually employ a cordon.

Differentiated charges are fairer from the point of view of charging users according to what they consume. With a flat rate cordon charge, short trips are penalised in relation to longer trips and vulnerable users who reside just outside the cordon but need to commute to the centre tend to pay more often. Charging peak and shoulder rates over the full period of the peaks, with reasonably fine differentiation, brings particular advantages. It enables road users to respond by advancing or delaying journey time. In principle no user need be priced-off the road when this option is available (Van den Berg, 2017), at least where traffic is not atrophied by hyper-congestion.

Box 2. Rule-based pricing in Singapore

Singapore's electronic road pricing system uses prices determined by optimisation of traffic flow. Prices are set to ensure traffic speeds are maintained at agreed levels: 20-30 km/h on arterial city roads, 45-65 km/h on expressways. Electronic Road Pricing rates are determined by a quarterly review of traffic speeds of priced roads and during the June and December school holidays. The pricing formula was developed using a traffic flow model developed by the Land Transport Authority. When speeds fall below the target levels prices are increased. When speeds rise above the target range, prices are reduced.

The benefit of this rule-based methodology is transparency. This aids understanding for both the public and decision makers and underpins public support for the system. It also permits prices to be set at the level needed to contain congestion and modified when needed, without having to revert to a political decision each time changes are required.

Regarding the congestion problem as a bottleneck, use can be priced to spread demand away from pinch points in time and space and allow all trips to be made. Some of the lowest income road users have the least flexibility in their schedules, so the principle may break down in relation to users of most concern in terms of social impact, but there is a much larger propensity to adjust schedules and trips than generally expected. This was demonstrated by monitoring of the responses to the closure of the Forth road bridge linking Edinburgh to the north of Scotland for maintenance (Marsden et al., 2016). This found retiming of trips was much higher than predicted.

Bottleneck congestion is probably the dominant feature in Auckland and other cities with a network of expressways running through the city. Access on and off the expressways is where a lot of congestion occurs. In such circumstance, applying a uniform charge misses the opportunity to spread the peak. A differentiated charge would achieve the same overall traffic reduction at an average price that is much lower than a flat rate charge (Van den Berg, 2017). Distributional effects are complex, but efficiency and equity tend to coincide more with variable pricing, with the availability of alternative modes of transport being less critical.

The effect of a congestion charge in sorting traffic, providing more space for those able and willing to pay, raises social equity issues. Bonsall and Kelly (2005) examine the impact of congestion charge design on social exclusion and at-risk groups. They examined the likely impacts of six hypothetical congestion charging schemes in Leeds, UK, modelling a synthetic population with highly disaggregate data on household composition and income by location from the Small Area Statistics of the UK National Household Census. They found that the distribution and severity of impacts on at-risk groups depend crucially on the precise definition of the charge area, the basis of the charges and the exemptions provided. Their modelling confirmed that charges proportional to distance driven within the charged area have less serious consequences for those at-risk than flat area fees or cordon charges. They also found that if a charge is based on crossing a cordon, the cordon can be adjusted to affect fewer at-risk people.

This type of detailed modelling can be used to go some way to design the system to mitigate impacts on at-risk communities and design any potential exemptions, although the study concludes it could be difficult to target help effectively. Road user charging will result in some lower income drivers reducing car use and others making economies elsewhere. Those most at risk are on low incomes with no realistic alternative to make essential journeys. The trip may be too long or their health too poor to undertake on foot or by bike, public transport service may not exist or be inaccessible to them. Factors for vulnerability include disability, age, gender, membership of a social minority and specific responsibilities for the transport of other people. More broadly, lower income jobs tend to have the least flexibility in terms of working hours, and people on low wages often have several places of work with need to travel between them, ruling out adjusting travel times as a response to road pricing.

The position of the cordon or boundary of the charging area and the way the charge is levied – cordon crossing or time and distance-based charge – combine to determine the spatial distribution of the drivers affected by the charging scheme and how much they pay. The number and location of at-risk drivers affected can vary greatly with scheme design as the data from Leeds demonstrates. Under one of the proposed cordon schemes examined, many affected at-risk drivers were located just outside the cordon boundaries. In this case park and ride systems might provide a feasible alternative for a significant proportion of regular trips. Under other schemes, however, the spatial distribution of origin and destinations of low income drivers affected was spread quite sparsely across the built-up area. This suggests that additional buses, or park and ride services to points just outside a cordon, would not offer a feasible alternative to use of the car.

Whilst expert design is important, ultimately political judgement will determine the type of congestion charging scheme adopted. It is therefore important that political decision makers and experts confer early on, so that politicians understand the design as it unfolds and in particular to avoid premature commitments to rule out or rule in features that might significantly hamper effective congestion management.

Fiscal impacts of road pricing and subsidies for public transport

Taxes that increase the cost of using cars, such as fuel taxes and congestion charges, may be regressive to the extent that they affect non-discretionary travel, e.g. travel to work where there is no viable alternative to the car. As with any consumption tax, they will account for a larger share of income or expenditure in low-income households than high-income households. However, most studies have found the regressive impact to be small (CBO, 1986; Poterba, 1991; Eliasson, 2016). McInnes (2017), in an examination of the distributive impact of environmental taxes and charges in G20 countries for the OECD, concludes that taxes designed to internalise external costs are among the least regressive forms of taxation. The study finds that taxes on transport fuels and congestion charges are progressive in most countries, except in specific situations, notably the working poor in high-income countries with high car ownership but limited public transport options. In Gothenburg, for example, public transport accounts for a relatively low share of commuting and low-income individuals typically travel by car. Middle and higher income earners are likely to pay lower fuel taxes over time as they switch to newer and more fuel efficient vehicles. In Gothenburg, where there is little congestion and the scheme mainly serves to raise revenue for infrastructure investment, the charge applies all day even though there is no congestion outside peaks. The system is regressive and creates a net welfare loss (Eliasson, 2016; West and Börjesson, 2017). In mitigation, any alternative revenue raising tax would have been equally regressive and the use of revenues for a large project with a low benefit cost ratio may, nevertheless, be a legitimate political decision.

How revenues from road pricing are used has a major impact on the overall distributive impact of road pricing. Revenues could be used to offset more distorting taxes, i.e. taxes that provide a disincentive for productive economic activity, or to offset regressive taxes elsewhere in the economy. More importantly, there are powerful fiscal mechanisms in widespread use to address social equity. The general taxation and social security system can be employed to mitigate any regressive effects of congestion pricing. This was a key finding of earlier work on road pricing reported to Transport Ministers (ECMT, 2003).

Small (1992) outlined three broad categories of revenue-allocation scheme to compensate those who are most adversely affected: monetary reimbursement to travellers as a group, for example reduction in road taxes; substitution for general taxes used to pay for transport services, for example a reduction in local property taxes; new transport services, for example improvements in public transport (for areas with under-provision) or highway improvements. How charging revenue is used can have a significant impact on how effects of pricing are distributed between user groups. Net impacts, accounting for the use of revenues, are the relevant outcome to model in assessing equity effect (Eliasson and Mattsson, 2006; Anable and Goodwin, 2018; D'Artagnan et al., 2018). Small (1992) argues that charging revenue is usually large enough to allow those who are most adversely affected to be more than fully compensated, providing a surplus to promote general social goals.

Within the transport sector, road pricing revenue can be used to provide alternatives to car use for non-discretionary travel – public transport and cycling infrastructure. In practice, existing public transport users in London, Stockholm and Singapore have benefitted from urban congestion pricing through additional bus and metro services and through improved speed and reliability of bus services. For cities where public transport services are currently inadequate, a package of measures that expand mass transit services and introduce peak pricing on these services at the same time as pricing road use will maximise overall benefits.

Taxing mobility is probably less distorting than taxing business to fund public transport. The revenues from London's relatively small area Congestion Charge are used for investment in transport in London, including buses, road maintenance and the metro system. But surcharges on business rates are being used to fund major public transport investments in London and Paris; Crossrail and the Metro de Grande Paris respectively. It would be more efficient to fund these investments through congestion charges across the cities' roads.

Paris has chosen to manage the scarce available space on its roads by restricting access through closing expressways. In a more fiscally constrained environment, for example if central funding were not available to contribute to the costs of public transport, the city might have preferred congestion charging. The availability of central government funding strongly affected the development of congestion charging plans in English cities. Advanced plans for congestion pricing in the East and West Midlands and in Bristol and Cambridge were dropped, and Manchester's congestion charging scheme was rejected in a 2008 referendum, in the context of a relaxation of conditions for making central funds available for transit investments. Freedom for local authorities to raise funds from congestion charges was granted by the Transport Act 2000, under the condition that any revenues were recycled in local transport projects. The Ministry of Transport then introduced a Transport Investment Fund in 2005 that provided for a total of GBP 9.5 billion of central funds for public transport, cycling and pedestrian projects for local authorities who installed congestion charging or workplace parking schemes (Butcher 2010; 2018). In the run up to the 2010 election it was announced that funds would be provided without the requirement to introduce congestion charging. The charging plans were politically contentious and removing the link to funding probably tipped the balance. Some of the cities subsequently started to work again on charging systems but the charging powers have only been used outside London for a small scheme to restrict access to the historic centre of Durham and to emissions-charging schemes in Brighton and Nottingham.

One thing congestion charging achieved in Stockholm was acceptance for a major expansion of public transport and how it should be expanded, something that had never been achieved before. The use of revenues for metro investment was beneficial even if benefit-cost ratios (BCRs) for those projects were low in comparison to road projects; it should be remembered that BCRs should be used to rank similar projects and are of limited use in comparing projects with very different characteristics.

Experience in Stockholm and elsewhere suggests that lasting improvements in public transport capacity have to be supported by both users and a broad range of taxpayers. In practice, all households will need to contribute to the subsidies necessary for investment and operation of public transport, and road pricing is likely to contribute only a limited part. At the same time the subsidies needed for public transport can be reduced and the incentives for efficiency provided by peak pricing preserved by targeting support to the users that need it most. Targeted subsidies have been used successfully in Bogota to protect the mobility of the poor through credits to electronic travel cards (ITF, 2017b).

The objective of congestion charging is to manage traffic rather than raise revenues, not least because there are cheaper ways to do that. Although the cost of the technology for pricing has fallen since the last review of charging options by the ITF (2010), fuel taxes are still cheaper to administer. From a technical point of view, congestion charging can certainly be part of a network-wide electronic road pricing system with revenue raising objectives, to pay for roads or to contribute to public finances more broadly. However, the peak prices necessary to manage congestion must not be tempered by any mechanism designed to set a limit on the overall revenues raised by generalised road pricing. If they are subject to a cap below the level required to manage demand they will be ineffective and discredited.

Assessing the distributional impacts of road pricing

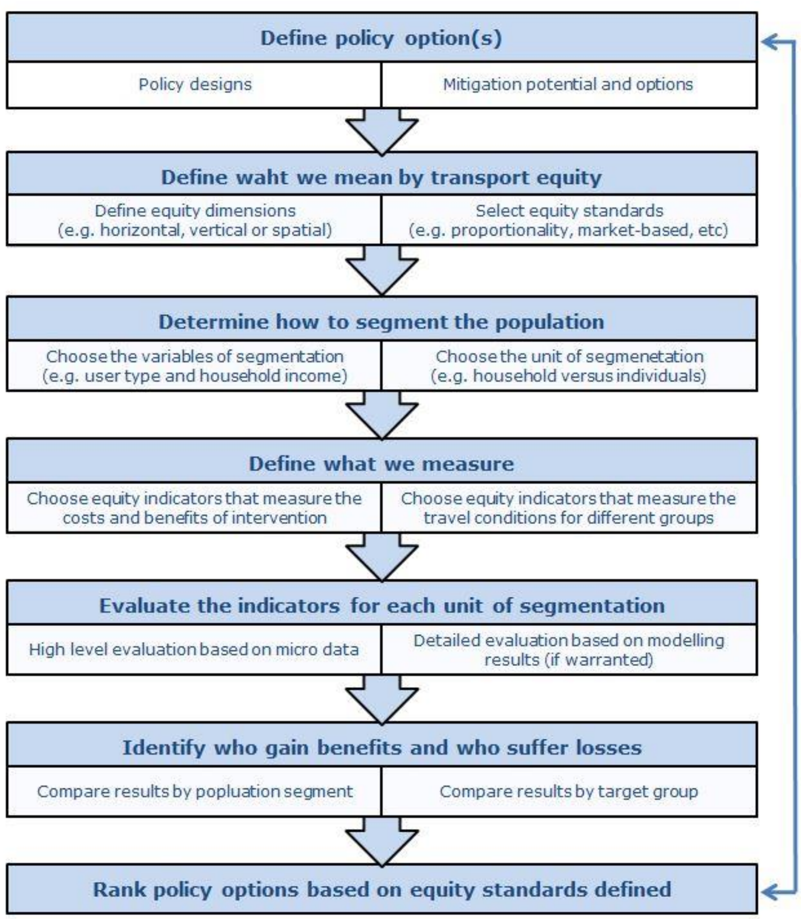
Establishing an assessment framework

Although the overall distributional impacts of road pricing may be small, pricing schemes can clearly have a large impact on some vulnerable households and individuals. Mitigating these effects or compensating vulnerable groups requires review of design options, quantifying impacts on different household types. One first needs to clarify the equity concepts at stake and explore the available options in a systematic way. This is the role of an assessment framework. New Zealand's Ministry of Transport is currently developing such a framework and will test it on case studies using existing transport modelling tools supplemented with additional census and household travel survey data. From an economic perspective, there is no single definition of equity. The literature on road pricing has historically focused on distributional impacts among income groups, as the question of whether road pricing is regressive, i.e. whether lower income groups pay more has been at the core of the debate. Yet equity is a broader concept and many other dimensions can be considered. For example, is the scheme offering consistent treatment for individuals in the same income group (horizontal equity)? What is the spatial distribution of winners and losers (territorial equity)? Some authors also argue for some form of temporal equity depending on how benefits and losses are distributed to the present or the future. In short there are several household segmentations to be considered.

Bills and Walker (2017) discussed an equity analysis framework (Figure 7) that makes use of disaggregated micro data (such as population, land use and travel behavioural data obtained from activity-based travel demand models) to overcome biases from aggregation. Their framework includes two crucial components - identifying an appropriate segmentation of the population and identifying the equity indicators to evaluate. The common equity indicators used in practice include accessibility, travel time, travel distance, mode share, distance travelled in congested conditions and traffic displacement. Segmentation of households may involve the use of one or more variables of segmentation (such as income and characteristics of the individuals or households) and a unit of segmentation (such as individual or household or geographic zone). Bills and Walker (2017) recommended selecting the variables of segmentation based on the chosen equity dimension (e.g. horizontal versus vertical equity). For the unit of segmentation, they recommended using smaller units to reduce aggregation bias.

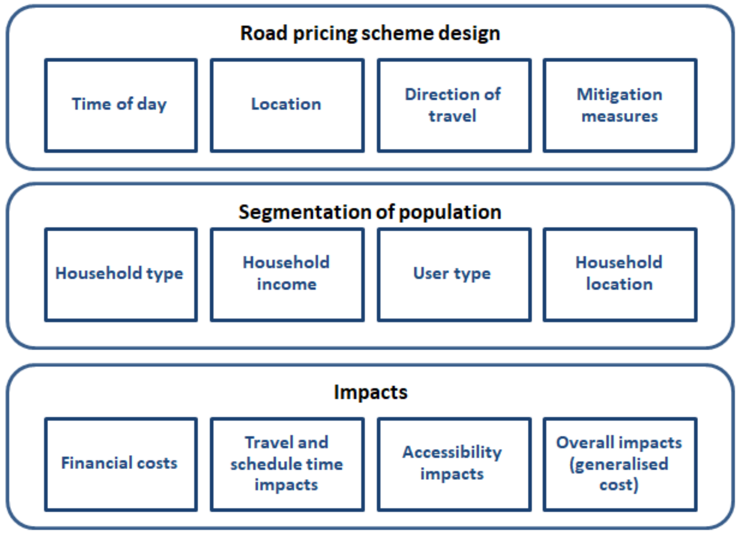
An assessment framework is important for screening options at an early stage of policy development and weeding out unpromising options, to allow analytical resources to focus on the main alternatives. Figure 8 summarises the dimensions an assessment framework needs to consider. Three of the most important aspects are: road pricing options and scheme designs, mitigation measures and use of revenue from congestion charging (both discussed in the previous section) and analytical dimensions to identifying vulnerability.

Figure 7. Distributional impacts assessment framework



Source*:* Based on Bills and Walker (2017).

Figure 8. Aspects to consider in an assessment framework



Source: Based on MRCagney (2017).

Analytical dimensions of vulnerability

Mattioli et al. (2017) define three dimensions of vulnerability, which can also be used to categorise the distributional impacts of road pricing (Table 3). The three vulnerability dimensions are exposure, sensitivity and adaptive capacity. Mattioli et al. define exposure as the cost burden of travel. This includes the level of vehicle ownership per household and household location. Sensitivity refers to ability to pay covering factors such as income, employment status and job type. Adaptive capacity refers to accessibility to alternative means of transport. Factors that influence the adaptive capacity include household type, demographic characteristics, physical constraints (e.g. physical disabilities) and availability of alternate modes of transport or routes for travel. Employment status and job type can sometimes play a role. There are also interactions between these factors.

Four basic types of at-risk groups can be identified form the nine factors summarised in Table 3:

1. low-income earners who have inflexible employment arrangements that constrain their freedom to choose departure and arrival times
2. households with young children who might need to meet both the children's education commitments and the adult's employment commitments at specific locations and times
3. people with physical constraints such as young children or elderly dependents and people with disabilities that constrain their ability to switch modes
4. households located in areas with no or limited access to public transport suitable to substitute for charged trips, which constrains their ability to switch modes.

As a result, there are five analytical dimensions to identifying which at-risk groups would be most adversely affected. The first four dimensions align with the four basic types of at-risk group, namely income, household type, user type and location. Time of day is the fifth component because trip generation rates vary with time.

Table 3. Vulnerability dimensions and at-risk groups

Factors	Vulnerability dimensions			At-risk groups
	Exposure (cost burden of travel)	Income (ability to pay)	Adaptive capacity (accessibility with alternatives)	
Vehicle ownership	●			Areas with no or limited access to public transport
Household location	●			
Income		●		Low-income earners with inflexible employment arrangement
Employment status		●	o	
Job type		●	o	
Household type			●	Households with young children
Demographic characteristics			●	Young children, elderly and people with disabilities
Physical ability (e.g. people with disabilities)			●	
Availability of alternate modes or routes			●	Areas with no or limited access to public transport to substitute charged trips

Source: Based on discussion in Mattioli et al. (2017).

Models for distributional analysis

Even simple pricing schemes can have unexpected impacts on behaviour, traffic flows and transport costs. Therefore most road pricing scheme have been designed with the help of large-scale modelling studies.

The standard approach to assessing how road pricing impacts transport demand relies on classical four-stage modelling: trip generation, trip distribution, mode choice and route assignment. Although this approach is an efficient way to forecast the impact on medium-term transport demand, it will be insufficient when it comes to understanding distributional impacts.

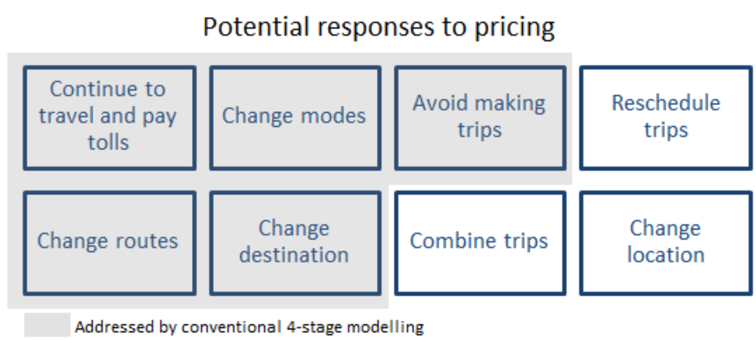
The first reason is that it does not allow for disaggregated analysis, which is essential for estimating distributional impacts. The second is the wide range of potential responses to pricing that should be considered. When road pricing is implemented, users might react in many ways as summarised in Figure 9. Depending on the scheme design and objectives, some reactions might more important to model than others, possibly making the use of conventional transport modelling irrelevant.

This section is divided in two parts. The first subsection discusses the data required as inputs to modelling, and more specifically argues that synthetic population data are required. The second focuses on modelling requirements.

Using micro data for disaggregated analyses

Transport practitioners have traditionally relied on mobility surveys to help design transport policies. But when it comes to identifying which households would be most vulnerable to road pricing, they are insufficient. As presented in the analytical framework section, the vulnerability of a household depends on at least five, cumulative dimensions. A low-income household will be much more impacted if it has no access to public transport and if one of the family members has physical disabilities. Even with a relatively high sample size, mobility surveys only allow estimation of one or two dimensions for a given location, with a rather crude spatial definition. While mobility surveys provide sufficient information to help estimate the travel behaviour within a neighbourhood or the proportion of low-income households in that neighbourhood, what it is really needed is the combination of the two – how low-income households travel – at a finer geographical scale – typically the census block.

Figure 9. Behavioural responses addressed by conventional models



Source: Adapted from MRCagney (2017).

The methodological answer is to synthesise a population. A synthetic population provides a microscopic representation of the actual population. It is built by combining aggregated and disaggregated data from multiple sources (e.g. different surveys, car ownership and use information or income data). Each individual is assigned to a precise residential location and the attributes of the synthetic population contain detailed information such as age, gender, work or study, car ownership as well as the complete travel pattern. The synthetic population is a simplified representation of the actual population, with the statistical characteristics of the true population. Synthetic populations have been used in the assessment of transport policies for some time and with the advent of large scale microsimulation, synthetic population generation has produced a vast scientific literature (see Farooq, Bierlaire, Hurtubia, and Flötteröd, 2013). A recent trend is the use of mobile phone data along with traditional survey data. Microsimulation has become a key tool for distributional assessment (see Box 3 for an example).

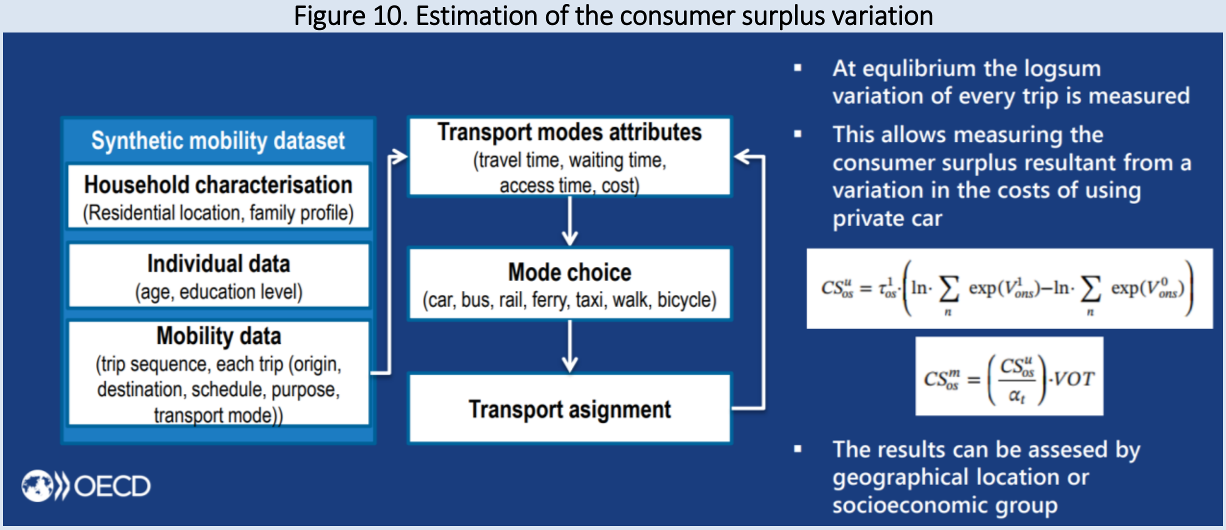
Building a synthetic population can provide initial insights into the distributional impacts of a charge even without explicitly modelling the impacts. This would typically be done by neglecting behavioural responses (mainly modal shift, rerouting and rescheduling) as in Bonsall and Kelly (2005), a practice that is sometimes referred to as static microsimulation.

Box 3. Synthesising a population for transport policy study

The International Transport Forum has recently assessed potential centralised door-to-door shared mobility services in Auckland (ITF, 2017a) using a microsimulation model. The synthetic population was generated from respondent-level data from Auckland's Household Travel Survey and uses an algorithm in three steps. First, it assigns a virtual household to each residential location by duplicating the characteristics of a sample respondent. It then generates for each virtual individual a trip chain that is plausible in the light of transport options that the individual has access to. Finally it introduces relatively small variations in trip destinations and schedules. The output is a full synthetic population with information on households (residential location, family profile), on individuals (age, education levels) and complete mobility behaviour (complete trip chains, including the origin-destination of each trip, timing, mode and purpose). In addition each individual is embedded with a utility function that summarises its transport preferences.

This last point is what makes ITF's approach to population generation well suited for policy assessment, especially where trip decisions are likely to be significantly affected by the policy. When road pricing is implemented, car users might shift to other modes, stop driving or reschedule their trips. Correctly valuing the impacts of these behavioural reactions is essential, but not necessarily straightforward. From an economic perspective the correct way of proceeding is to compute the surplus variation for each user. When trip decisions are modelled using rule-based approaches, which is the case of the majority of micro-simulators, this can be done only through numerical approximations. On the contrary, when trip decisions are modelled consistently with utility theory, as it is the case of ITF model, the consumer surplus can be derived directly, using the so-called "logsum" formula.

Figure 10. Estimation of the consumer surplus variation



Beyond the four-step model

There are three essential modelling requirements to support effective assessment of the social impacts of a transport policy. First, the forecasting tool should be able to capture how different individuals react to pricing. At a minimum, the heterogeneity in users' value of time should be explicitly modelled as it is central to the question of whether the pricing scheme is regressive. As pricing usually reduces travel times and increases monetary costs, the gains are larger for individuals with higher values of time. The net impact (of paying the charges) not only differs by trip purpose and traffic mix, it also differs by socio-economic group. In addition to heterogeneity in value of time, the difference in the preferences across socio-economic groups regarding modal choice and trip scheduling should also be taken in account.

A second requirement is the ability to model trip scheduling behaviour (considering heterogeneous values of schedule delay). This requirement is important when assessing time-differentiated pricing schemes. Such schemes usually induce peak spreading which in turn can result in non-trivial distributive impacts. Modelling this correctly requires dynamic traffic assignment (DTA) models which are not yet widely used by practitioners. However, DTA has already been successfully applied in one congestion charge study (De Palma and Lindsey, 2006) and results show that the costs and benefits of a time-varying tolling scheme are severely underestimated when rescheduling effects are ignored.

The third requirement is the ability to quantify trip reduction. An urban toll will reduce road traffic when users consolidate their trips (referred to as trip chaining), switch to a closer destination or simply cancel their trips. Understanding the underlying mechanisms and the structure of this mobility reduction is essential. One way to achieve this is to move toward an activity-based approach. Activity-based models derive travel demand from people's daily activity patterns. They predict which activities are conducted when, where, for how long, for and with whom, and the travel choices they make to complete the activities. Unfortunately, activity-based models have rarely been applied in practice for planning decisions, except in a couple of large US metropolitan areas.

There are two broad strategies to fulfil the three requirements:

- Calibrate a dedicated multi-agent microsimulation model. This allows modellers to specify any form of complex decision mechanism regarding mode-change, trip rescheduling, trip-chaining and destination substitution. The drawback is that microsimulations are often difficult to calibrate, they also lack theoretical properties (as typically behaviours are inferred from expert judgement rather than derived using observed preferences) and there might be data convergence issues.
- Extend an existing four-step model to incorporate more realistic – but more complex – behavioural features. This is an appealing solution as it has the benefit of using the existing tools and offers a smooth transition for modellers that can progressively develop their capabilities. However, the body of knowledge required for dynamic traffic assignment and activity-based modelling is still an ongoing field of research. Although the theoretical concepts are now settled, they are usually poorly reflected in commercial software.

In summary, there is no one size fits all solution regarding the optimal modelling approach. The skills of the modelling team, the level of development of an existing model and the precise objectives of the pricing scheme are local factors that should guide the decision on a case-by-case basis.

Conclusions on the design of road pricing to manage congestion

Perceived distributive impacts are a significant factor in public attitudes to road pricing. Cordon charges are often unpopular because they are seen as discriminating against commuters living outside the city centre and against shops located just inside the cordon. This was the case, for example, in the 2005 referendum that rejected a proposed cordon charge in Edinburgh. In Manchester, concern in the business community about the possible impact on the supply of labour and in turn competitiveness was a factor in dropping plans for a congestion charge. Consultation on distributional impacts and assessment of scheme design is therefore essential.

Discussions at the roundtable concluded that the overall distributive impacts of road pricing are small but that some vulnerable populations can be adversely affected, particularly by cordon charges. Cordons can be designed to minimise the numbers of vulnerable households adversely affected but differentiating charges to incentivise peak spreading is effective in minimising distributional impacts with all types of charging scheme.

Area-wide electronic vehicle-kilometre charges, differentiated in time and by location, are the most efficient form of congestion charge and have the lowest distributional impacts. Differentiation across peak times provides opportunities modifying departure times rather than being priced off the system and allows for lower average charges than would otherwise apply. Geography and nature of local travel patterns may mean a simple cordon can achieve most of the benefits of a more sophisticated charging system but in Auckland's case, where much of the congestion builds up at points of access to the motorway network differentiated distance based charges are likely to be the most efficient option.

Experience from Stockholm and London suggests that the public generally accepts road pricing once the system is introduced. Public opinion is certainly more favourable after implementation than before road pricing is introduced. This is partly because it is very difficult for people to judge the impact of something they have never experienced. The lesson from Sweden is that surveying public opinion before scheme introduction is not a reliable guide to acceptability. Many of the negative distributional impacts expected in Stockholm did not eventuate. For example, one-third of the discretionary trips disappeared without being noticed by survey respondents. This indicates the potential for trip consolidation and cancellation of non-essential trips whilst meeting basic travel needs.

A less direct factor in the acceptance of congestion pricing in Sweden has been linking grants from central government for large road investment schemes to the introduction of road pricing. The Stockholm scheme was part of a package for improving transport in the region that included investments in a ring road. This was a significant factor as under Swedish law, raising taxes (including those for investment in transport infrastructure) is a national (not a regional) prerogative. The Stockholm congestion charge is therefore legally classified as a national tax; local charges for using roads are not permitted to avoid the risk of local authorities charging for transit of their communities. As noted, tax competition between neighbouring cities was feared in Manchester, where the decisive factor in abandoning plans for road pricing was delinking it from funding for investment in the city's transport system. In Gothenburg, where congestion is rather limited in scale and distribution, the main interest for the local population was the accompanying package of measures including investment in a road tunnel, the funding for which is only partly compensated for by charging revenues. Congestion charging in

Stockholm also revolutionised attitudes to investment in public transport, opening the way to a major expansion of services previously unthinkable.

In Singapore, road pricing enjoys general support from the population. The key factor here is that charges are calculated to maintain target speeds, an approach that is understood and accepted. This has both made the policy apolitical and provided reassurance that tolls are not adjusted to increase revenues.

Emergency vehicles and cars used by people with disabled parking permits are universally exempt from congestion charging schemes. Buses are also generally exempt, except in Singapore (D'Artagnan et al., 2018). Beyond these limited categories, exemptions are not an effective strategy for mitigating social impacts. Leakage is a major problem, i.e. exemptions being used for non-targeted trips such as vehicles exempt because they carry a disabled users' badge being driven for other purposes. Bonsall and Kelly (2005) expected over 90% leakage in the congestion charging systems they examined. London granted a significant proportion of user discounts and exemptions. Residents from within the charging area are offered 90% discount. Taxis and minicab drivers are exempt but rapid growth in this sector with the advent of app-based ride services has driven a sharp increase in vehicle traffic in London. Today, discounted or exempted trips constitute around 50% of traffic crossing the charging zone (D'Artagnan et al., 2018). Exemptions for residents inside charging areas can be highly counterproductive. Exempting residents or providing large discounts defeats the object of managing demand for road space and of course foregoes a large part of potential revenue. The consequence is that charges must be much higher to have the same impact on overall levels of traffic.

To conclude, the following points drawn from the roundtable discussion are particularly relevant for Auckland in its deliberations on road pricing.

- Time- and space-based road pricing allocates road space according to the value attached to the trip. The resulting network performance improvements can deliver significant economic benefits with limited distributive effects. As the impact on vulnerable households tends to be scattered geographically, negative distributional impacts are better mitigated with targeted support for those affected than generalised discounts and exemptions.
- To understand the distributional impacts of road pricing and target mitigation measures, it is necessary to understand patterns of non-discretionary trips – who makes them, between what origins and destinations, and for what purposes. Using administrative and other micro data, it is often possible to identify vulnerable households based on microsimulation without sophisticated modelling. Microsimulation is also useful for setting cordons or boundaries of the charging areas to minimise rat-running and unintended distributive effects.
- Unlike many other major cities, Auckland has a low public transport share for commuting trips. The timing of investment in public transport will therefore be important to ensuring new services are available to substitute for car use on introduction of road pricing. For cities with already high shares of public transport use and low prices, introducing peak pricing on public transport at the same time as introducing road pricing brings the greatest welfare benefits. For Auckland, further investment in public transport services even without peak pricing can be expected to bring benefits due to current relative under-provision.
- Road pricing should be viewed as a crucial part of a package to achieve better utilisation of space in the city. Coupled with investment in public transport it will support transit-oriented urban development and may contain sprawl. Better utilisation of road space will ultimately make city living more attractive, reducing commuting time and air pollutant emissions, and should drive productivity by improving access to jobs across the region.

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List of participants

International experts

Ms Jillian ANABLE	University of Leeds, UK
Mr Arie BLEIJENBERG	Netherlands Organisation for Applied Scientific Research, Netherlands
Ms Maria BÖRJESSON	Swedish National Road and Transport Research Institute, Stockholm, Sweden
Mr Kian Keong CHIN	Land Transport Authority, Singapore
Mr Yves CROZET	University of Lyon, France
Mr Mark DARROUGH	Australian Department of Infrastructure & Regional Development, Australia
Mr Mans LÖNNROTH	Former State Secretary for Environment, Sweden
Ms Aurélie MERCIER	University of Lyon, France
Mr Stef PROOST	University of Leuven, Belgium
Mr Olivier QUOY	CEO, Atalandes, France
Mr Matthew SCHRODER	Australian Competition and Consumer Commission, Australia
Mr Vincent van den BERG	Free university of Amsterdam,Netherlands
Mr Ian WALLIS	Ian Wallis Associates Ltd, Wellington, New Zealand
Mr Scott WILSON	D'artagnan Pacific,United Kingdom and Australasia

New Zealand Ministry of Transport

Ms Kirstie HEWLETT	Deputy Chief Executive, Regulatory and Data Branch
Mr Tim HERBET	Manager, Domain Strategy, Economics and Evaluation
Mr Dan JENKINS	Manager, Analytics and Modelling
Ms Joanne LEUNG	Principal Economist, Domain Strategy, Economics and Evaluation
Mr Sandy FONG	Principal Strategy Adviser, Domain Strategy, Economics and Evaluation
Mr Ralph SAMUELSON	Principal Scientist, Analytics and Modelling
Ms Emily FULLHAM	Senior Adviser, Demand Management
Mr Anaru SILAO	Senior Adviser, Demand Management

New Zealand Treasury

Mr Dieter KATZ	Principal adviser, National Infrastructure Unit
Mr Jon BULTER	Senior adviser, National Infrastructure Unit

New Zealand Transport Agency

Ms Leigh MITCHELL	Director, Customer Experience and Behaviour
Mr Kevin WRIGHT	Practice Manager, Investment Assurance
Ms Jannette FARLEY	Principal advisor, Regulatory and Transport Policy
Ms Sarah CRONWRIGHT	Principal specialist, Statutory Planning & Community
Ms Kirsten TAYLOR	Communications

Auckland Transport, New Zealand

Mr Chris MORGAN	Group Manager, Analytics and Research
Ms Christine PERRINS	General Manager, Strategic Transport Planning
Mr John DAVIES	Manager, Auckland Forecasting Centre
Mr Jojo VALERO	Team leader Transport Modelling,Auckland Forecasting Centre
Mr Nik VORSTER	Transport Economist

Auckland Council, New Zealand

Mr David HAWKEY	Manager, Transport and Infrastructure Strategy
Mr David NORMAN	Chief Economist
Mr Alastair CRIBBENS	Principal Transport Advisor, Transport & Infrastructure Strategy
Mr Jesse ALLPRESS	Senior social researcher, Research and Evaluation Unit

Additional attendees

Mr Saeid ADLI	Auckland, New Zealand
Mr Michael BUSHBY	WSP Australia Pty Ltd, Australia
Ms Helen CHAPMAN	Greater Wellington Regional Council, Wellington, New Zealand
Mr Suh-wen CHIOU	National Dong Hwa University, Taiwan
Mr Stuart DONOVAN	MR Cagney, Auckland, New Zealand
Mr Simon DOUGLAS	NZ Automobile Association, Wellington, New Zealand
Ms Josephine DRAPER	Abley Transportation Consultants, New Zealand
Mr Pascal FELIX	WSP Australia Pty Ltd, Australia
Mr Bruce JAMES	Griffith University, Australia
Mr S.M. Sohel MAHMUD	The University Of Queensland, Australia
Mr Brendan O'KEEFFE	Brisbane City Council, Australia
Ms Janet STEPHENSON	University of Otago, New Zealand
Mr Doug WILSON	University of Auckland, New Zealand
Mr Jian XING	Nippon Expressway Research Institute Co Ltd., Japan

International Transport Forum, OECD

Mr Stephen PERKINS	Head of Research and Policy Analysis
Mr Jari KAUPPILA	Head of Statistics and Modelling
Mr Luis MARTINEZ	Policy Analyst
Mr Nicolas WAGNER	Policy Analyst

International Transport Forum

The Social Impacts of Road Pricing

This report assesses how road pricing impacts are distributed amongst citizens. It specifically examines how the reallocation of road space can improve the wellbeing of the community at large, looks at the relationship between road tolling and public transport pricing, and explores how simulation models can help develop measures to minimise negative impacts of road pricing. It also reviews current road pricing schemes in Sweden and Singapore. The report summarises the findings of an ITF Roundtable held in Auckland, New Zealand, in December 2017 that brought together 18 experts from eight countries.

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
+33 (0)1 45 24 97 10
contact@itf-oecd.org
www.itf-oecd.org

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